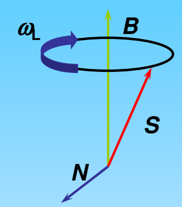
The Neutron Spin-Echo Technique

*The Neutron Spin-Echo (NSE) technique achieves high energy resolution by encoding the neutron energy into neutron spin Larmor precession angle. Polarized neutrons are sent through two identical magnetic fields (large solenoids) before and after the sample. At the sample a π spin flip occurs, either by a flipper or the sample itself. If the scattering process is strictly elastic the precession angles in the two fields are equal and opposite, so that full polarization is recovered, irrespective of the initial neutron velocity distribution. Small energy transfers lead to a change in the precession angle of the outgoing beam and, hence, to a decrease in the measured polarization. The intermediate scattering function **S(Q,t)** is directly determined by scanning the magnetic fields in the coils and measuring the polarization.*

Neutrons in magnetic fields: Precession

Neutron Properties

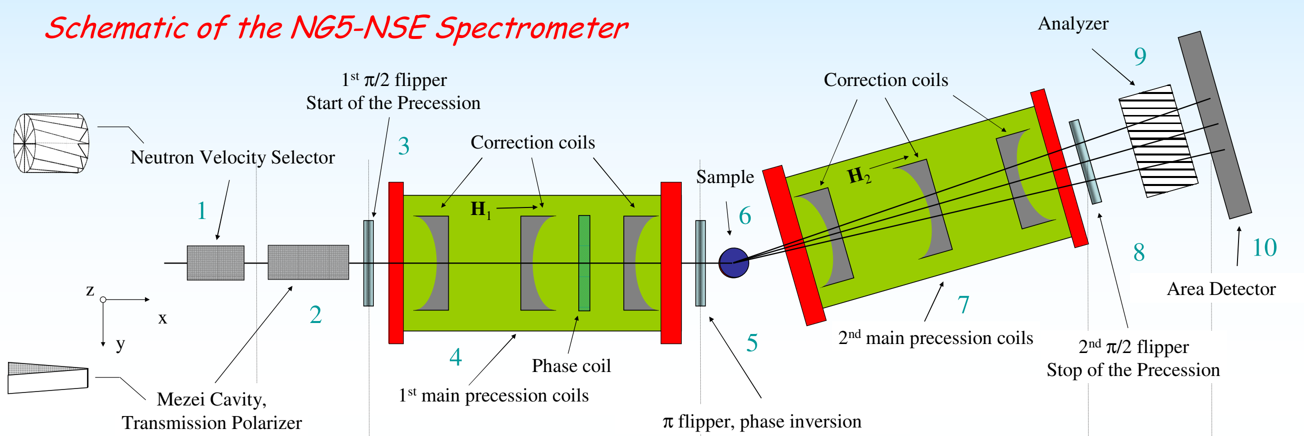
- Mass, $m_n = 1.675\times10^{-27}$ kg
- Spin, $S = 1/2$ [in units of $h/(2\pi)$]
- Gyromagnetic ratio $\gamma = \mu_n/[S\times h/(2\pi)] = 1.832\times10^{8}\ \mathrm{s^{-1}T^{-1}}$ (29.164 MHz T^{-1})



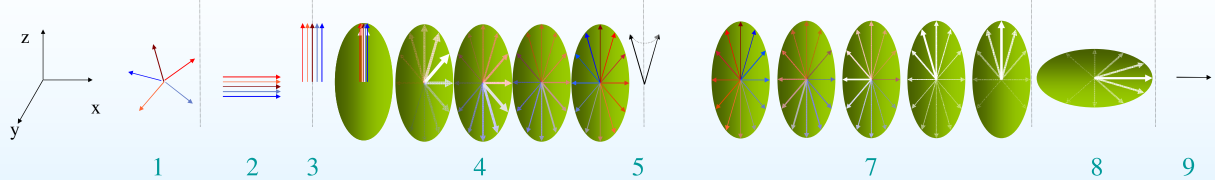
In a Magnetic Field

- The neutron spin (**S**) experiences a torque (**N**) from a magnetic field (***B***) perpendicular to its spin direction. $\Longrightarrow$ $\vec{N} = \vec{S}\times\vec{B}$
- Precession with the Larmor frequency: $\Longrightarrow$ $\omega_L = \gamma B$
- The precession rate is predetermined by the strength of the field only. $\Longrightarrow$ $\dfrac{d\vec{S}}{dt} = \gamma\vec{S}\times\vec{B} = \vec{S}\times\vec{\omega}_L$

Schematic of the NG5-NSE Spectrometer



Motion of the neutron beam spins in the spectrometer



In a Neutron Spin Echo Spectrometer…

1) *A velocity selector determines the mean velocity (wavelength) of the neutron beam, usually with a wavelength spread of the order of 10-20 %.*
2) *The beam goes through a polarizing device. A Mezei cavity in the case of NG5-NSE. Half of the neutrons are discarded and the transmitted neutrons have spins aligned to the velocity direction, x.*
3) *The first $\pi/2$ flipper changes the spin direction from the x to the z direction, perpendicular to the magnetic field of the main coils. The precession of the spins starts.*
4) *The neutron beam travels through the first precession coil. This coil produces a homogeneous field parallel to the direction of the neutron path. Each neutron spin will perform a Larmor precession around the magnetic field direction. Faster neutrons will spend less time than slow neutrons in the field and their final precession angle will be smaller. At the end of the first coil the neutron beam is completely depolarized. Each spin has performed as many as 10^5 turns.*
5) *The π flipper rotates the spin direction of 180° around the z axis. The y component of the spin change sign.*
6) *The neutron beam interacts with the sample. The neutrons will exchange momentum and energy with the sample, changing their direction and velocity. If the sample is not magnetic the spin status does not change.*

   For magnetic samples (paramagnet, antiferromagnet,…) the magnetic interaction flips the spins and the π flipper is not necessary. In this case the nuclear scattering gives a depolarized signal.
7) *The neutron beam goes through the second coil. Neutron that haven't changed their velocity interacting with the sample (elastic scattering) will regain their full polarization at the end of the second coil. Neutrons scattered quasielastically (small energy change, simmetrically distributed around the zero) will not fully regain the initial polarization. The final result will be a distribution of spin direction centered around the z-axis. The resulting polarization will be less than 1.*
8) *A second $\pi/2$ flipper projects the spin onto the xy plane for the analysis. The precession of the spins stops.*
9) *An analyzer composed of an array of supermirrors onto an absorber material, transmits the neutrons with probability proportional to the cosine of the angle between the spin direction and the z axis.*
10) *An area detector collects the resulting signal.*